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FAIRING COMPOSITIONS FOR AIRCRAFT SURFACES

By Philip S. Turner, Jewel Doran,
and Frank W. Reinhart
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SUMMARY

Fairing compositions are applied to aircraft surfaces, welds and junctions of metal plates, and rivet depressions to improve the aerodynamic efficiency of the airplane at high speeds. A critical problem involved in their use is the maintenance of satisfactory adhesion to the metal under the extremes of temperature, weathering, and vibration encountered in service. This report describes tests which were developed to evaluate fairing compositions and presents the results of measurements with experimental mixtures of various plastics, fillers, and solvents. Important factors in obtaining satisfactory performance are low moisture absorption, a softening temperature no higher than the temperature of application, and a coefficient of thermal expansion at low temperatures equal to that of the metal.

A method is described for formulating fairing compositions which have, within limits, desired coefficients of thermal expansion. The necessary proportions of fillers can be computed with constants determined from measurements with binary mixtures. Constants for commonly employed fillers are presented.

Fairing compositions which adhered satisfactorily to aluminum alloy when subjected to the accelerated service tests were formulated with vinyl acetate resin. A proposed composition consists of 20 parts vinyl acetate AYAF, 55 parts asbestine 3X, and 25 parts of zinc dust dispersed in a mixture of 2 parts ethyl ether and 1 part acetone to a solvent content of 20 percent.

INTRODUCTION

This report presents the results of an investigation to find a suitable plastic composition for filling depressions

on metal aircraft. These depressions occur at rivets, welds, and junctions of metal plates. Unless these depressions are properly filled, the aerodynamic efficiency of the airplane at high speeds is appreciably reduced. Materials for this purpose have been called rivet and depression fillers, fairing compositions, and aerodynamic smoothing compounds.

A satisfactory composition for this purpose should have the following characteristics:

1. Adherence to the metal when wet and when dry
2. Adherence to the metal at all temperatures between 71° C (160° F) and −57° C (−70° F)
3. Adherence to the metal when the structure is subjected to vibration
4. Good weathering properties
5. As low a density as possible
6. Nonhazardous in application or in service
7. Easy application
8. Dry or set quickly to a hard mass capable of being sanded readily
9. Ingredients commercially available

The first four characteristics are essential to satisfactory performance. A low density is desirable to keep the total weight added to the airplane as low as possible. The remaining characteristics are chiefly concerned with problems involving production and application of the fairing compositions. Since the satisfactory performance of aircraft is of primary importance, it was decided to find filling compositions which would give satisfactory performance under simulated service conditions and then to study the application characteristics of the most promising ones.

Between May 1939 and September 1941 outdoor exposure tests were made on plastic compositions for filling depressions on metal surfaces. The specimens of vinyl acetate resin composition were in excellent condition at the end of the exposure tests. These tests indicated that satisfactory fairing compositions based on plastic materials could be developed to withstand ground conditions encountered in Washington, D. C.

In a previous report (reference 1) an analysis of factors involved in maintenance of adhesion of plastic to metals indicated that matching of thermal expansivities would improve the resistance of the bond to thermal changes. Hence, particular attention was given during the course of this work to formulating fairing compositions which would have thermal expansivities approximating those of aluminum.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

MATERIALS

The plastic materials used in this investigation are described in table 1. The fillers worked with during the course of this investigation are described in table 2. Commercial fairing compositions which were included in the investigation for comparative purposes are identified in table 3.

Various plasticizers, selected on the basis of data obtained during previous work on other projects, were used in some of the compositions. The plastic materials, plasticizers, and fillers were mixed with various solvents and ground together in a ball mill to form experimental fairing compositions. The experimental compositions were formulated on the basis of the principles indicated in this report. A purely empirical investigation would have involved several times the number of compositions which were included in this work.

TESTING PROCEDURES

Simulated Service Tests

To evaluate the performance characteristics of the fairing compositions, accelerated service or aging tests were devised and used. These tests include (1) immersion in water, (2) exposure to low temperature and room temperature in alternating cycles, (3) accelerated weathering, (4) vibration, and (5) a cyclic combination of heat, ultraviolet light, fog, and low temperature. In general, compositions which were not satisfactory in one test were not subjected to subsequent tests.

The specimens for these tests were prepared by applying the filling compositions to indentations on 0.012-inch-thick aluminum-alloy sheet and allowing them to dry for at least 3 days.

To estimate the effect of water on the adherence of the fairing compositions to the metal, the specimens were immersed in water by 25° C (77° F) for 24 hours, removed, and examined.

To estimate the effect of low temperature, specimens were placed on dry ice in an insulated box for 30 minutes, removed, and allowed to stand at room temperature for 30 minutes. One cold and one warm exposure period constituted a cycle, which was repeated 30 times or until failure occurred as indicated in the tables.

To estimate the effect of weathering, specimens were subjected to the 240-hour sunlamp-fog accelerated weathering test described in method No. 6021 of Federal Specification L-P-406a entitled "Plastics, Organic: General Specifications, Test Methods."

To estimate the effect of vibration at low temperatures, specimens were vibrated in an insulated box as cantilever beams through an angle of 3° at 1800 oscillations per minute. Dry ice was placed in a wire basket around the vibrating specimen for 1 hour and was removed for the next hour. A fan was used to circulate the air within the box during the cold part of the cycle and air taken in from the surrounding room during the warm part of the cycle. The temperature fell to −40° C (−40°F) within 20 minutes after the dry ice was placed in the box and rose to 0° C (32° F) within 5 minutes after the ice was removed. The minimum temperature obtained in each cycle was approximately −65° C (−85° F) and the maximum was approximately 25° C (77° F). The cycle of conditions was repeated as many times as is indicated in the tables.

To estimate the combined effects of heat, ultraviolet light, high humidity, and low temperature, specimens were subjected to the following cyclic test:

Condition	Period of exposure (hr)	Description
A	15	Ultraviolet light and heat from an S-1 sunlamp; method No. 6021 of Federal Specification L-P-406a; temperature approximately 65° C (149° F).
B	2	Fog.
C	1	Approximately -30° C (-22° F).
A	2	See A above.
B	2	See B above.
C	1	See C above.

The periods of exposure to the various conditions were adjusted so that the specimens were exposed to condition A for a total of 200 hours, to condition B for 40 hours, and to condition C for 20 hours.

It was found that some compositions which were satisfactory at -30° C (-22° F) were not satisfactory at lower temperatures. Consequently, in the latter part of the work, instead of placing the specimens in an atmosphere maintained at approximately -30° C (-22° F) for condition C, they were placed directly on a piece of dry ice in an insulated box.

Water Absorption

The water absorption of the plastic materials was determined by method No. 7031 of Federal Specification L-P-406a.

Thermal Expansion and Softening Temperature

The specimens used in these tests were molded bars approximately 7.5 by 0.5 by 0.2 inch. The length was measured to the nearest 0.01 inch. The specimens were conditioned at 25° C (77° F) and 50 percent relative humidity prior to testing.

The mean coefficient of linear thermal expansion was measured with the equipment shown schematically in figure 1. The measurements were made by starting at a low temperature,

about −75° C (−105° F), and raising the temperature approximately 1° C per minute. The rate of increase in temperature was controlled by regulating the heat output of the electric heating coils with an external rheostat. The temperature of the specimen under test was measured with a thermocouple and a potentiometer. The measurements were made by setting the potentiometer for regular temperature intervals and recording the extension when no deflection of the galvanometer pointer was produced by opening and closing the potentiometer circuit. By plotting the extension in length against temperature, a curve was obtained from which the mean coefficient of linear thermal expansion was determined. A correction factor of $0.3 \times 10^{-6}/^{\circ}C$ for the range −50° to 0° C was added for the expansion of the fused quartz tubes. The method of measurement is essentially that described in National Bureau of Standards Research Paper RP 29. It is possible to obtain an accuracy of better than 2 percent with this type of equipment.

The expansivity determined from a cooling curve is essentially the same as that determined from a heating curve, if the temperature of the specimen remains below its softening temperature. At temperatures slightly below the softening temperature of the material, dimensional changes will occur which reflect the prior mechanical and thermal history of the specimen. A similar phenomenon has been observed in measurements of the expansivity of vitreous enamels at much higher temperatures (reference 2). This difficulty is not encountered in the case of vinyl acetate resin because its softening temperature (or annealing temperature) is very close to ordinary room temperatures. Because of the nature of the mechanical measuring system the value obtained from the heating curve is considered to be the more reliable. The rate of heating also is easier to control than the rate of cooling.

The coefficient of thermal expansion of a material is not the same for all temperature ranges; it generally increases with an increase in temperature. For practical purposes, the coefficient of thermal expansion may be assumed to be a constant below the softening range. The validity of this procedure is indicated by the curves in figure 2.

The softening range is indicated by a change in the slope of the expansion-temperature curve followed by a decrease in length of the specimen. The lower limit of the softening temperature range thus defined indicates the beginning of appreciable plastic flow under the influence of the nominal stress imposed by the measuring system. The upper limit

indicates the temperature at which the rate of plastic flow exceeds the expansion. These softening temperature ranges are in good agreement with the values obtained in this laboratory by another method and with recent data reported in the literature (reference 3) for unfilled plastics. The results do not always agree with softening temperature or heat distortion points determined by other methods.

RESULTS OF TESTS

Water-Immersion Tests

The results of the water-immersion tests are given in table 4. Typical water absorption data for the various plastics are given in table 5. It is observed that the compositions which adhered initially and during the water immersion contained cellulose nitrate, vinyl acetate resin, methyl methacrylate resin, styrene resin, and thermoplastic phenolic resin. The cellulose nitrate compositions which were satisfactory contained 20 percent glycol sebacate or 20 percent methyl phthalyl ethyl glycolate with solvent No. 3. The adhesion of the vinyl acetate compositions was uniformly good. The best adhesion of styrene was obtained when applied with heat, although the material crazed on cooling. The thermoplastic phenolic resin was porous and weak initially. The behavior of methyl methacrylate resin was erratic.

None of the cellulose acetate, cellulose acetate propionate, cellulose acetate butyrate, thermosetting phenol-formaldehyde, urea-formaldehyde, or melamine-formaldehyde compositions had satisfactory adhesion. The failure of the cellulose derivatives in the water-immersion tests appears to be caused by the large dimensional changes resulting from the absorption of water. The extent of dimensional changes has been shown to correlate well with the hygroscopicity of the plastic (reference 4). The urea-formaldehyde and melamine-formaldehyde plastics separated from the metal in the process of curing before the water-immersion tests were started.

Thermal Expansion and Softening Temperature

The coefficients of thermal expansion and softening temperature ranges of some of the plastic materials which

were subjected to the water-immersion tests were determined and are reported in table 6.

The effect of several fillers in reducing the expansivity of vinyl acetate compositions is shown by the data in table 7. The most efficient of these fillers for reducing the coefficient of thermal expansion of vinyl acetate resin are the asbestines. It should be noted also that the various types and amounts of filler affect the softening temperature range to different extents.

Temperature-Cycle Tests

On the basis of these data on the coefficients of thermal expansion of various plastics and fillers, compositions were formulated and applied to aluminum sheet. The specimens were subjected to alternate exposure to room temperature and low temperature. The results obtained with the vinyl acetate resin compositions are given in table 8, those obtained with the styrene compositions are given in table 9, and those obtained with the cellulose nitrate compositions are given in table 10. Two types of failure were observed. The failure of thick coatings usually began by the plastic separating from the metal at the edges of the coating. The failure of thin coatings usually began with a crack in the plastic. Only thin coatings of unfilled plastics withstood more than 1 cycle of freezing and thawing. Cellulose nitrate plasticized with 20 percent methyl phthalyl ethyl glycolate (Santicizer M-17) withstood 30 cycles of freezing and thawing when the film was less than 13 mils thick; thicker coatings separated from the metal after a few cycles.

The results in these tables indicate that as the thermal expansivity is made to approach that of the metal by the addition of fillers, the resistance to exposure at low temperature is improved. The results for specimens 11, 12, 13, 17, and 18 in table 8 appear to be exceptions, but it should be noted that the filler settled during the drying period which resulted in a higher concentration of filler in the plastic layer adjacent to the aluminum. These coatings also were thinner than most of the applications of other materials. The high filler concentration lowers the coefficient of thermal expansion of that part of the plastic. The expansivities given in the tables are for uniformly mixed compositions. The agreement between the behavior in the freezing-thawing test and the behavior expected on the basis of expansivity also is good for the styrene and cellulose nitrate compositions.

The compositions which gave satisfactory results in the freezing-thawing test were subjected to the sunlamp-fog cyclic accelerated weathering test. The results are given in table 11. None of the styrene or cellulose nitrate compositions was satisfactory. Most of the vinyl acetate resin compositions were satisfactory in this test.

The compositions which were satisfactory in the previous tests were subjected to (1) the vibration test and (2) the combined heat-ultraviolet light - high humidity - low temperature test. Three commercial materials and several additional experimental compositions were also subjected to these tests. The results are given in tables 12, 13, and 14. The results of these two tests did not differ significantly from those of previous tests.

Density

The results of density measurements made on dried specimens of several experimental and commercial products are given in table 15.

DISCUSSION OF RESULTS

The typical failure of the filling compositions encountered in the simulated service tests was separation of the bond between the metal and the plastic. The stresses causing the bond to break arose, in most cases, from the difference between the dimensional change of the plastic composition and that of the metal when the specimens were subjected to the various tests.

Causes of Separation of Fairing Compositions from Metal

There are three principal factors which cause dimensional changes tending to separate the plastic from the metal. They are as follows:

(1) Shrinkage of the plastic composition by volatilization of plasticizers or of retained solvent, or by further polymerization. All these may be classed under the single heading Shrinkage on Aging.

(2) Swelling and shrinkage of the plastic caused by the absorption and desorption of moisture

(3) Expansion and contraction resulting from changes in temperature

Adhesion failures frequently result from the shrinkage caused by loss of solvent (reference 5). This usually occurs during the drying stage. The shrinkage usually can be controlled by a choice of solvents. Diluents should be avoided since they tend in many cases to cause excessive shrinkage. (See references 6 and 7.) The addition of some slowly evaporating solvent which lowers the yield point so that plastic flow will take place in the plane of the film during drying should be included in the solvent formulation. This also provides a longer time for the plastic flow to take place. Slowly evaporating solvents do not seem to be needed with materials which have low softening temperature ranges, such as vinyl acetate resin. Application of thick pastes containing a minimum amount of solvent also reduces the shrinkage.

The shrinkage caused by loss of plasticizer is not immediately apparent in service since the rate of loss usually is very slow. Plasticizers cause the plastic to flow more readily by reducing the elastic yield point and by lowering the softening temperature range. As the plasticizer is lost during aging, the elastic yield point at room temperature, and the softening temperature range will rise and may reach the point at which the plastic may have no appreciable flow at ordinary temperatures. This is shown by the successive increases in the softening temperature range of cellulose nitrate compositions containing 15 percent methyl phthalyl ethyl glycolate heated for different lengths of time at 50° C (table 6). Vinyl acetate resin has a distinct advantage over some other plastics in that its softening temperature range without plasticizer is low enough to permit plastic flow under the influence of small stresses at room temperature.

Dimensional change resulting from a change in moisture content is an inherent property of a plastic material and is roughly proportional to the amount of moisture absorbed or desorbed. Fillers which absorb very little moisture tend to reduce the amount of moisture absorbed by the plastic composition. Therefore, when dimensional stability is desired, the use of mineral fillers is indicated.

Dimensional changes resulting from differences in coefficients of thermal expansion may be responsible for the failures of the bonds at temperatures below the softening

temperature range of the plastic composition (reference 8). If it is assumed that the deformation of the metal is negligible, the tensile stress in the film can be estimated from the coefficients of thermal expansion of the plastic and of the metal and the modulus of elasticity of the plastic. At temperatures below the softening temperature range, the plastic flow is slow, and as the temperature decreases the yield point increases. Assuming that (1) the change of temperature occurs at such a rate that the plastic flow is negligible or (2) the stresses produced are below the elastic limit of the plastic, the unidirectional tensile stress in the film may be estimated from the following equation:

$$\text{Tensile stress} = (A_a - A_b)(T_1 - T_2)E_a \qquad (1)$$

where

A coefficient of thermal expansion

E modulus of elasticity

T temperature

Subscripts a and b refer to plastic and metal, respectively, and 1 and 2 refer to different temperatures.

This equation is valid only at temperatures below the softening temperature range since the plastic flow will be appreciable under small stresses above this temperature range. Plastic flow of the material will relieve some of the stress. It also should be noted that this equation gives only that part of the tensile stress on the film resulting from the change of temperature from T_1 to T_2. Appreciable stresses may arise on going from the softening temperature to T_1 and from dimensional changes resulting from drying, aging, or variations in moisture content. The shearing force at the bond can be estimated by multiplying the stress by the thickness and the width of the plastic film.

The force required to maintain the length of a film attached to the metal would be greater than that calculated from equation (1) because of the lateral constraint. These tensile forces must be sustained in shear by the bond between the metal and the film.

Control of Stresses Resulting from Thermal Changes

The stresses arising from a change in temperature (equation (1)) of a plastic-metal combination may be reduced (1) by making the coefficient of thermal expansion of the plastic composition as nearly equal to that of the metal as possible, (2) by reducing the modulus of elasticity of the plastic composition, (3) by lowering the softening temperature range of the plastic. The shearing forces can be reduced by the use of thin plastic films. Control of film thickness is not practicable for this application.

The coefficient of thermal expansion of a plastic composition is determined by (1) the plastic, (2) the fillers, and (3) the plasticizers. Since these factors also control the modulus of elasticity and the softening temperature range, any change in formulation to obtain a change in one of these properties will result in changing the other two properties. The addition of fillers to plastics usually reduces the coefficient of thermal expansion. The data presented in table 6 show that the magnitude of the effect is different for each specific filler as well as being dependent on the amount of filler. The variation of expansivity of mixtures of vinyl acetate resin and aluminum powder is shown graphically in figure 3. The points for curve A are the weighted averages on a volume basis; the points on curve B are the weighted averages on a weight basis; curve C represents the experimental results. These curves show that the coefficient of thermal expansion of a plastic composition is not usually the average calculated from the expansivities of the individual constituents in the composition and the portion of each in the mixture. The coefficients of thermal expansion of vinyl acetate resin mixed with zinc yellow, bronze powder, quartz, and asbestine, respectively, are shown graphically in figure 4. Figure 5 shows the expansivity of mixtures of polystyrene and asbestine.

The following equation has been found to represent the experimental curves in figures 3, 4, and 5:

$$A_m = \frac{A_r C_r P_r + A_f C_f P_f + \cdots}{C_r P_r + C_f P_f + \cdots} \qquad (2)$$

where

A coefficient of thermal expansion

C a constant

P proportion by weight

Subscripts:

m mixture

r resin or plastic

f filler

This equation is of the same form as that given in a previous report (reference 1). The constant C appears to be proportional to the bulk modulus of elasticity divided by the density. The proportionality factor is also dependent on the shape and size of the particles and on the distribution of the material in the matrix. It was assumed that the constant C for each specific filler and each plastic was independent of the other components of a mixture if the ingredients are evenly distributed.

Constants determined by the use of equation (2) for binary mixtures are given in columns 5 and 6 of table 16. The ratio of the derived constant C to the bulk modulus of elasticity divided by the density for the various fillers is shown in column 7 of table 16. The fillers with the higher ratios reduce the coefficients more in proportion to their potential capacity than those with lower ratios when the various fillers are used in equal amounts and are uniformly distributed. The ratio appears to depend on the shape and size of the particles.

Many of the plastic-filler mixtures investigated for use in filling rivet depressions were formulated from the constants in table 16 and calculations made with equation (2). In most instances the calculated values were very near the measured values. These results are presented in table 17.

The specimens used to make the measurements of coefficient of thermal expansion contained none or very little solvent. The compositions as applied will contain at first a large amount of solvent, which will result in a higher coefficient of expansion. (See table 8, specimens 30 to 33.) This solvent content will decrease rapidly on aging, thus bringing the coefficient close to the limiting value. The retained solvents also cause a decrease in the softening temperature range and undoubtedly in the modulus of

elasticity. This will result in reducing the stresses; while the coefficient of thermal expansion of the plastic is higher than that of the metal.

A low modulus of elasticity is particularly important when resistance to vibration and impact is required. While the incorporation of fillers increases the modulus of elasticity at room temperature, the modulus of the filled plastic remains fairly constant to very low temperatures; whereas the modulus of an unfilled plastic increases rapidly with a decrease in temperature (reference 9).

METHODS OF APPLICATION

Two methods of application were considered: (1) the hot-melt method, and (2) the solvent method. Vinyl acetate resin compositions were used in most of this work.

Vinyl acetate resin compositions can be readily applied by spreading with a spatula when the metal and the plastic are heated to 120° to 150° C. Other plastic compositions also can be applied by this method, although some compositions may require heat and pressure. One advantage of this method is the very short setting time required before the material can be sanded satisfactorily. Two disadvantages are: (1) it has been reported that the corrosion resistance of aluminum alloys is decreased by heating at these temperatures, and (2) it is not practicable to heat large metal structures and pieces for this purpose.

Attempts were made to apply the hot plastic compositions to cold metal, but the results were not satisfactory. The composition cools so rapidly when it comes into contact with the cold metal that the bond is broken as soon as it is formed, even though the composition is capable of considerable plastic flow above room temperature. The rate of plastic flow is not high enough tocompensate for the thermal contraction.

The usual method of applying fairing compositions is with solvents. Since the hot-melt method did not appear to be practicable at the present time, the solvent method was investigated. Acetone and mixtures of acetone and ether were found to make the fastest drying vinyl acetate resin compositions. These solvents do not adversely affect the

performance characteristics as shown by the various tests. Sufficient solvent is used to make a thick paste which can be readily applied with a spatula. The vinyl acetate resin compositions may be applied by a spray gun if the mixture is thinned sufficiently with solvent. The thinner for spraying should contain some slowly evaporating solvent, such as Cellosolve. Pastes made with methyl acetate were found to dry almost as rapidly as those made with acetone. The addition of 5 to 10 percent of Cellosolve serves to keep the paste from drying too rapidly after removal from the container or in the open can pending application. The addition of Cellosolve also improves the working qualities of the paste, but lengthens the drying time. To speed drying, it was found advantageous to subject the plastic compositions to radiation from infrared lamps after some air-drying. The effects of various solvents used with vinyl acetate resin compositions are shown in table 14.

In attempting to shorten the drying time required before sanding, it was observed that increasing the percentage of fillers, particularly asbestine, was very effective. The highly filled material can be sanded while the resin still contains a considerable amount of solvent. This effect was utilized in preparing compositions to meet drying time requirements specified by aircraft manufacturers. The higher filler content raises the softening temperature and makes the material less flexible.

SERVICE TESTS

Compositions made of 40 parts of vinyl acetate resin (Vinylite AYAF), 55 parts of asbestine 3X or 5X, and 5 parts of aluminum powder were selected initially for service tests. Sufficient acetone was added to make a thick paste. These compositions which were found to have an expansivity of approximately $28 \times 10^{-6}/^{\circ}C$ (aluminum has an expansivity of approximately $22 \times 10^{-6}/^{\circ}C$) withstood 30 warm-cold cycles without failure and also withstood successfully the other simulated service tests. Samples of these compositions were submitted to the Chance-Vought Division of United Aircraft Corporation, to the Naval Air Experimental Station at Philadelphia, Pa., and to the U.S. Naval Air Station at Norfolk, Va., for evaluation. The Chance-Vought Division reported that the composition dried too slowly and had a tendency to skin in thick sections and that the application and working properties were not good. The Norfolk Air Station reported that the composition dried too fast in the

can on handling and too slowly in thick sections and that the composition was difficult to handle.

These results indicated that faster drying time and better working properties were necessary. One of the most effective methods of producing faster drying mixtures and of improving working properties is by increasing the filler content. Since the mixture of 40 parts of vinyl acetate resin and 55 parts of asbestine gives a composition which has an expansivity nearly equal to that of aluminum, the addition of aluminum does not affect it very much. Compositions therefore were investigated in which the proportion of aluminum powder was increased. Because of the form of the aluminum powder (flat plates) the adhesion to the metal base was reduced and the drying time was increased slightly.

An increase in the proportion of asbestine decreases the drying time but also decreases the expansivity. Consequently, a mixture of 20 parts of vinyl acetate resin and 55 parts of asbestine, which gives a composition with an expansivity less than that of aluminum, was compounded with 25 parts of zinc dust, which raised the coefficient of thermal expansion to 22 x $10^{-6}/^{\circ}C$. The net result of this change was to increase the filler content from 60 to 80 percent by weight. The wet fairing composition consisted of 80 percent solids and 20 percent solvent, which was a mixture of 2 parts ethyl ether and 1 part acetone. Aluminum strips coated with this composition dried as rapidly as the Acme glazing putty (the fastest drying commercial product tested) and passed the 260-hour accelerated service test; strips coated with the Acme product will not pass the accelerated service test.

The sample of Opex glazing putty listed in table 3 was received for test after the completion of this experimental work. This putty successfully withstood 30 alternate cycles of exposure to dry ice and room temperature and the 240-hour accelerated weathering test. The putty has a high coefficient of thermal expansion, 54 x $10^{-6}/^{\circ}C$ for the temperature range -50° to -5° C, but a low softening temperature range, -5° to 5° C. It is rigid at -18° C (0° F).

By application of the tests and principles described in this report it may be possible to develop other fairing compositions as satisfactory as or superior to those resulting from this investigation. All the plastics were not investigated thoroughly because of lack of time. When this work was started, many of the synthetic rubbers, which

appear to have some of the properties necessary for this application, were not available.

CONCLUDING REMARKS

On the basis of the present investigation the following concluding remarks regarding fairing compositions for aircraft surfaces are made:

The essential characteristics of a satisfactory rivet filler for aluminum alloy are as follows:

(1) Low moisture absorption

(2) A softening temperature range approximately the same as or lower than the temperature prevailing during the drying period

(3) A coefficient of thermal expansion at low temperature approximately equal to that of aluminum and aluminum alloys, 19 to 23 $\times 10^{-6}$ per degree centigrade

(4) Excellent resistance to aging; the essential properties should not change appreciably on aging

(5) Satisfactory application properties

The softening temperature range of a plastic is reduced and the thermal expansivity is increased by the presence of plasticizers or retained solvents.

The softening temperature range of a plastic is increased and the thermal expansivity is reduced by the incorporation of fillers. The proportion of filler required to give a particular coefficient of thermal expansion can be computed with constants determined from measurements made on binary mixtures, by means of the following equation:

$$A_m = \frac{A_r C_r P_r + A_f C_f P_f + \cdots}{C_r P_r + C_f P_f + \cdots}$$

where A is the coefficient of thermal expansion, C is a

constant, P is the proportion by weight, and the subscripts m, r, and f refer to mixture, resin, and filler, respectively. Fillers with particles which are acicular or in the form of small flat plates are the most effective in reducing thermal expansivity. Spherical particles have the least effect.

Filled vinyl acetate resin compositions have been formulated which adhere to aluminum alloy when subjected to a series of drastic accelerated service tests, including vibration at temperatures alternating between −65° C (−85° F) and 25° C (77° F). Commercial fairing compositions which were tested separated from the metal when subjected to these conditions. Examples of two such vinyl acetate compositions are (1) vinyl acetate resin AYAF, 40 percent; asbestine 5X, 55 percent; and powdered aluminum, 5 percent; and (2) vinyl acetate resin AYAF, 20 percent; asbestine 3X, 55 percent; and zinc dust, 25 percent.

National Bureau of Standards,
Washington, D. C., July 1944.

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TABLE 1. DESCRIPTION OF PLASTIC MATERIALS USED IN THE INVESTIGATION OF FAIRING COMPOSITIONS.

Sample Designation	Material	Manufacturer	Manufacturer's Designation	Viscosity[a]	Description
CN-1	cellulose nitrate	E. I. du Pont de Nemours and Co.	PX 7551	1/2 second	
CN-2	cellulose nitrate	E. I. du Pont de Nemours and Co.	PX 7100	9 seconds	Nitrogen 11.87%
CN-3	cellulose nitrate	E. I. du Pont de Nemours and Co.	PX 7182	84 seconds	
CA	cellulose acetate	Tennessee Eastman Corp.	E-309	25-35 seconds	acetyl 40-40.7% 2.50-2.57% equivalents hydroxyl ——— 0.50-0.43% equivalents
CAP	cellulose acetate propionate	Eastman Kodak Co.	Eastman 101943	527 centipoises	acetyl 16.1% 1.17% equivalents propionyl 32.9% 1.80% equivalents hydroxyl ——— 0.03% equivalents
CAB	cellulose acetate butyrate	Eastman Kodak Co.	Eastman 101939	300 centipoises	acetyl 32.0% 2.25% equivalents butyryl 15.4% 0.66% equivalents hydroxyl ——— 0.09% equivalents
VA-1	vinyl acetate resin	Carbide and Carbon Chemicals Corp.	AYAA	27.5% solids	
VA-2	vinyl acetate resin	Carbide and Carbon Chemicals Corp.	AYAF	21.0% solids	
VA-3	vinyl acetate resin	Carbide and Carbon Chemicals Corp.	AYAT	18.0% solids	
PS	polystyrene	Monsanto Chemical Co.	Lustron		
MM-1	methyl methacrylate resin	Rohm and Haas Co. and E.I. du Pont de Nemours and Co.			cast polymerized sheet.
MM-2	methyl methacrylate resin	E. I. du Pont de Nemours and Co.	No. 28121		cast polymerized sheet.
MM-3	methyl methacrylate resin	American Solvents Corp.			compression molded from mixture of monomer and polymer.
TP	thermoplastic phenolic resin	Durez Plastics and Chemicals, Inc.	5116 Durez Adhesive		
PF-1	phenol-formaldehyde resin	Bakelite Corporation	Bakelite XO 11749		cured with 45% catalyst XX 11753
PF-2	phenol-formaldehyde resin	The Resinous Products and Chemical Co.	Amberlite PR-14		unfilled resin molded at NBS
UF	urea-formaldehyde resin	The Resinous Products and Chemical Co.	CB 550, cold set		unfilled resin molded at NBS
MF	melamine-formaldehyde resin	American Cyanamid Co.	Melmac Resin, cold set R-112		unfilled resin molded at NBS

a. The viscosity values were obtained in the manufacturers' laboratories by the following variety of methods (in parts by weight unless otherwise noted):

Cellulose nitrate series CN-1,-2,-3: A.S.T.M. falling ball method, using 20% solution in acetone (A.S.T.M. Standards, Part II, 1942).

Cellulose acetate CA: A.S.T.M. falling ball method.

Cellulose acetate propionate CAP: A.S.T.M. falling ball method.

Cellulose acetate butyrate CAB: A.S.T.M. falling ball method.

Vinyl acetate series VA-1,-2,-3: Percentage solids required to give a viscosity of 110 ± 10 centipoises at 20°C in methyl isobutyl ketone.

TABLE 2. DESCRIPTION OF FILLERS USED IN THE INVESTIGATION OF FAIRING COMPOSITIONS.

Material	Manufacturer	Manufacturer's Designation	Description
aluminum, powdered	Acme Bronze Powder Co.	Fed. Spec. TT-A-476, Amend. 3, Type A	
aluminum, filings			140 mesh and finer 43% 100-140 mesh 35% 70-100 mesh 22%
aluminum oxide, fused			
bronze, powdered	Baer Brothers	gold No. 661	
carbon	Columbian Carbon Co.	Micronex	
china clay	J. Lee Smith and Co.		approx. 45% SiO_2 40% Al_2O_3 14% loss on ignition 1% miscellaneous
ferric oxide	C. K. Williams	indian red	approx. 98% Fe_2O_3
glass, fibers	Owens-Illinois Glass Co.	bulk textile silk	
glass, powdered			bottle glass, ground in ball mill 16 hours
glass, powdered			ground Pyrex glass, 140 mesh max.
gypsum			$CaSO_4.1/2\ H_2O$
iron, powdered	Chas. Hardy, Inc.		200 mesh
iron, powdered	Advance Solvents and Chemical Corp.		manufactured by iron carbonyl process
lead oxide, red	John T. Lewis Bros. and Co.		Pb_3O_4
lead, white	Eagle-Picher Lead Co.		basic lead carbonate
magnesium silicate (mineral)	International Pulp Co.	Asbestine FT	325 mesh residue 0.5% oil absorption ——
magnesium silicate (mineral)	International Pulp Co.	Asbestine 5X	325 mesh residue 0.7% oil absorption 25.1%
magnesium silicate (mineral)	International Pulp Co.	Asbestine 3X	325 mesh residue 1.0% oil absorption 20.4%
magnesium silicate (mineral)	International Pulp Co.	Asbestine CC	325 mesh residue 2.5% oil absorption 12.0%
Portland cement			
quartz, fused, powdered	The Carborundum Co.	fused quartz	
silica, powdered			300 mesh
silicon carbide	The Carborundum Co.		60 mesh
silicon carbide	The Carborundum Co.		220 mesh; random particle size
silicon carbide	The Carborundum Co.	FF	FF; very fine
titanium dioxide	Titanium Pigment Corp.	Titanox A	anatase
zinc dust A	Mallinckrodt Chemical Works		
zinc dust B	American Smelting and Refining Co.		
zinc dust C	J. T. Baker Chemical Co.		
zinc oxide	New Jersey Zinc Co.	XX-601	acicular type
zinc oxide	New Jersey Zinc Co.	XX-503	round type
zinc yellow	Krebs Pigment and Color Corp.	X467-D	$K_2O.4ZnO.4CrO_3.3H_2O$

TABLE 3.- COMMERCIAL FAIRING COMPOSITIONS TESTED

Material	Manufacturer
Acme Glazing Putty	Acme White Lead and Color Co.
Bostik Cement No. M 356	B. B. Chemical Co.
Tuf-On No. 12, Spot Filler	Wipe-On Corporation
Tuf-On No. 15, Streamline Filler	Wipe-On Corporation
Valentines Nitro-Valspar	Valentine and Co.
Opex Glazing Putty	Sherwin-Williams Co.

TABLE 4. RESULTS OF WATER IMMERSION TESTS ON PLASTIC COMPOSITIONS.

Composition Designation	Plastic	Weight g.	Plasticizer[a] or Filler - Weight g.	Solvent[b] - Weight g.	Adhesion after 24 hr. immersion in water at 25° C
1	cellulose nitrate CN-2	30	TPP 2	No. 1 100	failed
2	cellulose nitrate CN-2	16	GS 4	No. 2 80	failed
3	cellulose nitrate CN-2	16	SM-17 4	No. 2 80	failed
4	cellulose nitrate CN-2	16	TPP 4	No. 2 80	failed
5	cellulose nitrate CN-2	16	GS 4	No. 3 80	good
6	composition 5 with zinc chromate primer undercoat				erratic - blushing
7	cellulose nitrate CN-2	16	SM-17 4	No. 3 80	good
8	composition 7 with zinc chromate primer undercoat				erratic - blushing
9	cellulose nitrate CN-2	16	TPP 4	No. 3 80	failed
10	cellulose acetate	16	TCP 4	No. 4 80	failed
11	cellulose acetate	16	SM-17 4	No. 4 80	failed
12	cellulose acetate	16	TCP 4	No. 5 80	failed
13	cellulose acetate	16	SM-17 4	No. 5 80	failed
14	cellulose acetate propionate	16	3GH 4	No. 6 80	failed
15	cellulose acetate propionate	16	TBC 4	No. 6 80	failed
16	cellulose acetate propionate	16	SM-17 4	No. 6 80	failed
17	cellulose acetate propionate	16	3GH 4	No. 7 80	failed
18	cellulose acetate propionate	16	TBC 4	No. 7 80	failed
19	cellulose acetate propionate	16	SM-17 4	No. 7 80	failed
20	cellulose acetate propionate	16	3GH 4	No. 8 80	failed
21	cellulose acetate butyrate	20	TPP 2	No. 9 100	failed
22	cellulose acetate butyrate	16	3GH 4	No. 6 80	failed
23	cellulose acetate butyrate	16	TBC 4	No. 6 80	failed
24	cellulose acetate butyrate	16	SM-17 4	No. 6 80	failed
25	cellulose acetate butyrate	16	3GH 4	No. 6 80	failed
26	cellulose acetate butyrate	16	TBC 4	No. 8 80	failed
27	cellulose acetate butyrate	16	SM-17 4	No. 8 80	failed
28	vinyl acetate VA-2	15	Al powder 6	No. 10 25	good
29	vinyl acetate VA-2	74.6	(Al oxide 5.4 (Al powder 20	No. 11 —	good
30	vinyl acetate VA-2 with zinc chromate primer undercoat			No. 11 —	good
31	vinyl acetate VA-2	40		No. 12 —	good
32	vinyl acetate VA-2	40		No. 13 —	good
33	vinyl acetate VA-2	40		No. 14 60	good
34	vinyl acetate VA-2	40		No. 15 60	good
35	styrene with zinc chromate undercoat			No. 16 —	questionable
36	styrene	95	DBP 5	No. 16 —	failed
37	styrene	95	DBP 5	Applied with heat	good
38	methyl methacrylate MM-1			No. 11 —	erratic
39	methyl methacrylate MM-1			No. 14 —	good
40	methyl methacrylate MM-1 with zinc chromate primer undercoat			No. 11 —	questionable-- blushing
41	methyl methacrylate MM-1 with zinc chromate primer undercoat			No. 17 —	questionable - blushing
42	phenol-formaldehyde, thermoplastic				good
43	phenol-formaldehyde, thermosetting, cured cold with catalyst		Micronex 20		failed
44	urea-formaldehyde, cured cold with catalyst				separated before test
45	melamine-formaldehyde, cured cold with catalyst				separated before test

a. Identification of plasticizers:

TPP - triphenyl phosphate
GS - glycol sebacate
SM-17 - santicizer M-17
TCP - tri-o-cresyl phosphate
3GH - triethylene glycol di-2-ethylbutyrate
TBC - tributyl citrate
DBP - dibutyl phthalate

b. Identification of solvent mixtures (parts by weight):

No. 1. methyl ethyl ketone 25, ethyl acetate 50, diacetone alcohol 10, butyl acetate 15.
No. 2. acetone 8, ethyl acetate 16, toluene 40, diacetone alcohol 16.
No. 3. acetone 40, methyl ethyl ketone 32, diacetone alcohol 8.
No. 4. acetone 32, methyl ethyl ketone 20, ethyl acetate 20, ethyl lactate 8.
No. 5. acetone 32, methyl ethyl ketone 20, ethyl acetate 20, diacetone alcohol 8.
No. 6. acetone 32, methyl ethyl ketone 32, diacetone alcohol 16.
No. 7. acetone 32, methyl ethyl ketone 32, ethyl lactate 16.
No. 8. diacetone alcohol 8, nitropropane 72.
No. 9. methyl ethyl ketone 75, diacetone alcohol 15, Cellosolve 10.
No. 10. ethyl acetate 19, butyl acetate 6.
No. 11. acetone
No. 12. butyl acetate 14.4, ethyl acetate 45.6.
No. 13. butyl acetate 15, methyl ethyl ketone 45.
No. 14. nitropropane.
No. 15. nitropropane 48, butyl acetate 12.
No. 16. butyl acetate.
No. 17 acetone 50, nitropropane 50.

TABLE 5.- MOISTURE ABSORPTION OF VARIOUS PLASTICS

Plastic	Moisture absorption[a]	Source of data[b]
Cellulose nitrate	0.6 - 2.3	PC
Cellulose acetate	2.0 - 4.0	PC
Cellulose acetate butyrate	1.6 - 2.1	PC
Vinyl acetate VA-2, unfilled	1.16	NBS
55 percent asbestine, 5 percent aluminum, powdered	1.15	NBS
55 percent asbestine, 25 percent zinc dust	.81	NBS
Styrene	0.00 - 0.05	PC & NBS
Methyl methacrylate	0.4 - 0.5	PC
Phenol-formaldehyde, unfilled	0.1 - 0.2	PC
Urea-formaldehyde	1.0 - 3.0	PC
Melamine-formaldehyde	1.0 - 1.7	PC

[a]Determined in accordance with method No. 7031 of Federal Spec. L-P-406a.
[b]PC - Plastics properties chart in 1944 Plastics catalog.
NBS - National Bureau of Standards.

TABLE 6. THERMAL EXPANSIVITY AND SOFTENING RANGE OF UNFILLED PLASTICS WITH AND WITHOUT PLASTICIZERS.

Specimen No.	Plastic[a]		Plasticizer		Thermal Expansivity -50° to 0°C	Softening Temperature range
	Type	Amount %	Type	Amount %		
					10^{-6}/°C	°C
1	CN-1	80	SM-17	20	55.0	28-40
2	CN-2	93.75	TPP	6.25	79.2	40-61
3	do.	80	SM-17	20	73.6-74.1	25-37
4	Same as 3 but dried at 50°C for 32 hr[b]				55.1	43-49
5	Same as 3 but dried at 50°C for 48 hr				53.2	47-54
6	CN-2	85	SM-17	15	64.0	35-40
7	do.	90	do.	10	94.1	40-44
8	do.	95	do.	5	89.4	45-52
9	CN-3	80	do.	20	93.2	37-42
10	VA-1 as received				75.3[c]	23-30
11	VA-1 baked 16 hr at 105°C				74.0	30-32
12	VA-2 as received				80.2-82.2[d]	15-20
13	VA-2 baked 16 hr at 105°C				74.3-76.3[d]	28-38
14	VA-3 as received				78.7	17-23
15	VA-3 baked 16 hr at 105°C				72.5	30-35
16	PS				66.6	55-82
17	PS dissolved in ethyl acetate, air dried, and baked 16 hr at 105°C				76.5	55-67
18	PS	95	DBP	5	70.1	55-72
19	MM-2				71.4[e]	97-100
20	MM-3 thin sample				91.8[e]	70-79
21	MM-3 thicker sample				95.1[e]	67-78
22	PF-2				38.8-39.6[f]	
23	MF				43.8[g]	
24	UF				42.5[g]	

[a]The plastics are identified and more fully described in table 1.
[b]All other samples of cellulose nitrate were air dried and then dried for 16 hr at 50°C.
[c]Samples about three years old.
[d]Measurements on specimens from different batches.
[e]For range of temperatures 20° to 50°C.
[f]The lower expansivity represents a longer curing period.
[g]Samples cured without solvents at 300°F.

TABLE 7. THERMAL EXPANSIVITY, SOFTENING TEMPERATURE RANGE, AND RESISTANCE TO EXPOSURE AT LOW TEMPERATURE OF COMPOSITIONS CONTAINING 50% VINYL ACETATE RESIN VA-2 and 50% FILLER

Specimen Number	Pigment	Density[a] of Pigment	Amount by Volume (%)	No. of Cold-Warm Cycles before Failure	Coefficient of Linear Thermal Expansion, -50° to 0°C (10^{-6}/°C)	Softening Range (°C)
1	Lead oxide, red	9.0	11.7	2	65.1	23-28
2	Zinc dust	7.1	14.3	-	64.5	28-30
3	Lead, white	6.7	15.1	10-30	62.1	28-32
4	Zinc oxide (round)	5.57	17.7	20	56.9	23-33
5	Zinc yellow (chromate)	3.53	25.3	2	56.8	---
6	Ferric oxide	5.15	18.8	4-30	51.0	33-35
7	Portland cement	-	-	5-30	49.1	18-23
8	Silica, powdered (300 mesh)	2.66	31.0	4-20	45.6	20-27
9	Titanium oxide (anatase)	3.9	23.4	>30	45.5	35-38
10	Bronze, powdered	8.6	12.1	-	45.2	---
11	Zinc oxide (acicular)	5.57	17.7	>30	45.2	31-37
12	Carbon, Micronex	2.25	34.6	>30	39.5	38-42[b]
13	Aluminum, powdered	2.7	30.6	>30	38.1	25-30
14	Quartz, fused, powdered	2.14	35.8	-	37.5	23-28
15	Asbestine FT	2.58	31.6	-	37.0	32-35
16	China clay	2.6	31.4	-	36.7	37-40
17	Asbestine 3X	2.58	31.6	>30	35.7	33-37
18	Asbestine 3X[c]	2.58	31.6	>30	35.5	23-28
19	Asbestine CG	2.58	31.6	-	34.8	37-40
20	Asbestine 5X	2.58	31.6	>30	31.5	37-40
21	Asbestine 5X[c]	2.58	31.6	-	30.8	33-37
	Vinyl Acetate AYAF[d]			1-2	74.3-76.3	28-38
	Aluminum 2-S				21.6-21.7	---

a. Data obtained from - Gardner, Henry A.: Physical and Chemical Examination of Paints, Varnishes, Lacquers and Colors, Ninth Edition, May 1939, and

Handbook of Chemistry and Physics, Twenty-Fourth Edition, 1940-1941.

b. Transition to rubberlike material.

c. Specimen prepared from different batch of ingredients.

d. Material baked 16 hours at 105°C to remove volatile impurities.

TABLE 6. PROPERTIES OF FILLED VINYL ACETATE RESIN COMPOSITIONS.

Specimen Number	Composition: Resin Type	Resin Amount (%)	Filler Type	Filler Amount (%)	Additional Filler or Plasticizer Type	Additional Filler or Plasticizer Amount (%)	Expansivity -50 to 0°C (10^{-6}/°C)	Softening Range (°C)	Cold-Warm Cycles before failure[a]	Remarks
1	VA-1	40	Asbestine 5X	55	Aluminum, powdered	5	25.6	35-40		
2	VA-2	70	Aluminum, filings	30			57.3		27-30	
3	do.	80	Aluminum oxide, fused	20			66.1	15-25		Composition not baked
4	do.	80	do.	20			62.1	25-30	6	Composition baked
5	do.	25	Asbestine FT	75			21.1	35-50		
6	do.	35	Asbestine 5X	65			24.1	38-40		
7	do.	31.6	do.	68.4			20.4	32-37		
8	do.	25	Asbestine 3X	75			21.4	33-43	> 30	
9	do.	35	Bronze, powdered	65			36.7	28-37		
10	do.	9	do.	91			21.9	> 110[d]	> 30	Chalking
11	do.	83.3	Glass fibers	16.7			55.1	28-32	1	Difficult to apply
12	do.	35	Glass, bottle	65			51.4	38-37	> 30	
13	do.	28	Glass, Pyrex	72			20.2-20.3	36-42		
14	do.	30	Iron, powdered 200 mesh	70			50.0	23-28	> 30 [b]	Filler particles concentrated in portion next to metal
15	do.	30	Iron, powdered (carbonyl)	70			57.6	23-28	> 30 [b]	do.
16	do.	25	Silica, powdered	75			28.4	25-33		
17	do.	70	Silicon carbide, 60 mesh	30			95.5	28-32	> 30 [b]	Filler particles concentrated in portion next to metal
18	do.	70	Silicon carbide, 220 mesh	30			53.1	28-32	> 30 [b]	do.
19	do.	70	Silicon carbide FF	30			51.1	28-32	> 30 [b]	do.
20	do.	25	Zinc yellow	75			44.3	30-52		
21	do.	47.5	Carbon, Micronex	50	Plasticizer 30H	2.5	44.0	42-47[d]	> 30	Difficult to apply
22	do.	42.5	do.	50	do.	7.5	56.4	38-46[e]		do.
23	do.	21.25	do.	75	do.	3.75	24.7	70-75[f]	> 30	do.
24	do.	50	Asbestine FF	25	Asbestine OO	25	35.2	28-32	> 30	
25	do.	74.6	Aluminum, powdered	20	Aluminum oxide	5.4	51.1	20-25	> 30	
26	do.	50	Asbestine 5X	35	Aluminum, powdered	15	36.0	32-37	> 30 [b]	
27	do.	40	do.	55	do.	5	27.7	37-40	> 30 [b]	
28	do.	40	do.	55	do.	5	32.7	3-10		Air-dried; contained 3.5% acetone
29	do.	40	do.	55	do.	5	32.2	8-11		Air-dried 1 week
30	do.	40	do.	55	do.	5	30.7	10-13	> 30	Air-dried 4 hr; infrared baked for 10 min. at 80°C
31	do.	40	do.	55	do.	5	28.1	28-30		Cast specimen, baked 16 hr at 105°C to remove solvent
32	do.	30	do.	65	do.	5	20.3	35-42		
33	do.	15	do.	75	do.	10	14.4			
34	do.	15	do.	75	Gypsum	10	13.6			
35	do.	20	do.	60	Zinc dust A	20	20.5	28-32		
36	do.	20	do	55	Zinc dust B	25	20.8-20.9	28-48		
37	do.	20	do.	45	do.	35	22.4	28-42		
38	do.	40	Asbestine 5X	55	Aluminum, powdered	5	27.9	38-37		
39	do.	23.8	do.	71.4	Zinc dust A	4.8	21.0	32-40		
40	do.	20	do.	55	do.	25	21.9	35-45		
41	do.	20	do.	55	Zinc dust B	25	21.8-23.5			
42	do.	20	do.	55	Zinc dust C	25	21.6	35-42		
43	do.	22.7	do.	68.2	Zinc yellow	9.1	21.4	30-40		
44	do.	50	Bronze, powdered	35	Aluminum, powdered	15	42.4	25-32	> 30 [b]	
45	do.	35	do.	50	do.	15	36.1			
46	VA-3	25	Asbestine FF	75			19.8	28-40		
47	do.	30	Asbestine 5X	70			21.3	35-40		
48	do.	24.5	Asbestine FF	73.5	Aluminum, powdered	2	20.0-20.2	38-38		
49	do.	40	Asbestine 3X	55	do.	5	29.8	35-40		

a. Mixtures were applied with heat and pressure unless otherwise indicated.

b. Applied with solvents.

c. Gradual transition 50° to 80°C.

d. Transition 23° to 27°C.

e. Transition 5° to 15° C.

f. Transition 10° to 20°C.

TABLE 9. THERMAL EXPANSIVITY, SOFTENING TEMPERATURE RANGE, AND RESISTANCE TO EXPOSURE AT LOW TEMPERATURE OF FILLED POLYSTYRENE COMPOSITIONS.

Specimen Number	Composition					Expansivity -50° to 0°C (10^{-5}/°C)	Softening Range (°C)	Cold-Warm Cycles Before Failure[a]	Remarks
	Amount of Polystyrene (%)	Filler		Additional Filler or Plasticizer					
		Type	Amount (%)	Type	Amount (%)				
1	26	Asbestine 3X	74			23.3		30[b]	
2	50	do.	50			34.4		30[c]	
3	47.5	Aluminum, powdered	25	Asbestine 3X Plasticizer DBP	25 2.5	35.9	60-75	—	
4	50	do.	50			37.1			
5	70	Asbestine 3X	30			45.2	72-88	1	Conditioned in desiccated atmosphere.
6	70	do.	30			45.8			Conditioned at 50% relative humidity.
7	56	Aluminum, powdered	25	Aluminum oxide Plasticizer DBP	15 4	46.9	53-57	30[d]	
8	66.5	Asbestine 3X	30	Plasticizer DBP	3.5	52.8			
9	100					76.5[e]		1	

a. Materials applied to aluminum alloy 248-RT with heat and pressure. In other tests, referred to in footnotes b to e, inclusive, the following solvents were used to apply the materials to Duralumin:
Solvent A: Ethyl acetate 90, butyl acetate 130, xylene 90, toluene 130 parts.
Solvent B: Ethyl acetate.

b. Material withstood 15 to 30 cycles when applied with solvent A.

c. Material withstood 4 to 30 cycles when applied with solvent B.
and 4 to 12 cycles when applied with solvent A.

d. Material withstood 1 to 30 cycles when applied with solvent B.

e. Styrene dissolved in ethyl acetate, baked 16 hours at 105°C to remove solvent.

TABLE 10. THERMAL EXPANSIVITY, SOFTENING TEMPERATURE RANGE, AND RESISTANCE TO EXPOSURE AT LOW TEMPERATURE OF FILLED CELLULOSE NITRATE COMPOSITIONS.

Specimen Number	Composition					Expansivity -50° to 0°C (10^{-6}/°C)	Softening Range (°C)	Cold-Warm Cycles Before Failure	Remarks
	Amount of Cellulose Nitrate CN-2 (%)	Filler		Additional Filler or Plasticizer					
		Type	Amount (%)	Type	Amount (%)				
1	42.6	Asbestine 3X	54.5	Plasticizer TPP	2.8	46.5	42 to 47		Pigment clumped.
2	60.0	Aluminum, powdered	25.0	Plasticizer SM 17	15.0	48.4	30 to 36	Failed before test.	
3	61.0	do.	20.0	Aluminum oxide Plasticizer TPP	15.0 4.0				
	First determination					53.7	35 to 85	> 30	Conditioned at 50% relative humidity.
	Second determination					50.5	Not determined.		Desiccated atmosphere conditioning.
	Third determination					52.2	do.		Conditioned 44 hours at 100% relative humidity.
	Fourth determination					53.7	do.		Conditioned 1 week at 100% relative humidity.
4	Valentines Nitro-Valspar					49.4[a]	-28 to -13		Initial length measured at -17.7°C(0°F).

a. Temperature range -70° to -30°C.

TABLE II. ACCELERATED WEATHERING TEST ON FAIRING COMPOSITIONS APPLIED TO ALUMINUM ALLOY, 248-RT.

Specimen Number	Composition						Observations Regarding Adhesion and Condition[a]
	Plastic		Filler		Additional Filler or Plasticizer		
	Type	Amount (%)	Type	Amount (%)	Type	Amount (%)	
1	VA-2	70	Aluminum, powdered	30			Separated from metal after 117 hrs light, 24 hrs fog.
2	do.	50	do.	50			Satisfactory; some chalking.
3	do.	74.6	do.	20	Aluminum oxide	5.4	Satisfactory
4	do.	50	Asbestine 3X	50			do.
5	do.	25	do.	75			Edge loose after 156 hrs light, 34 hrs fog; no further damage.
6	do.	9	Bronze, powdered	91			Satisfactory; chalking.
7	do.	35	Glass, bottle	65			Satisfactory
8	do.	30	Iron, powdered (carbonyl)	70			do.
9	do.	50	Lead oxide, red	50			Pitted after 79 hrs light, 48 hrs fog; adhesion satisfactory
10	do.	50	Lead, white	50			Satisfactory
11	do.	47.5	Carbon, Micronex	50	Plasticizer 30H	2.5	do.
12	do.	50	Portland cement	50			do.
13	do.	70	Silicon carbide FF	30			do.
14	do.	50	Titanium dioxide	50			do.
15	PE	50	Aluminum, powdered	25	Aluminum oxide Plasticizer DBP	15 4	Completely separated after 154 hrs light, 30 hrs fog.
16	do.	50	Asbestine 3X	50			Partly separated after 156 hrs light, 34 fog.
17	do.	26	do.	74			Partly separated after 156 hrs light, 34 fog.
18	CE-2	80	do.		Plasticizer SM-17	20	Applied with solvent[b]; blistered after 79 hrs light, 18 hrs fog; badly discolored; separation after 156 hrs light, 34 hrs fog.
19	do.	70.3	Aluminum, powdered	25	Plasticizer TPP	4.7	Applied with solvent[b]; completely separated after 99 hrs light, 24 hrs fog.

a. Compositions were applied to the metal with heat and pressure unless otherwise indicated.

b. The solvent mixture was as follows: Acetone 40, methyl ethyl ketone 32, diacetone alcohol 8 parts.

TABLE 12. ADHESION OF FAIRING COMPOSITIONS TO ALUMINUM ALLOY 24S-RT DURING VIBRATION AT ALTERNATE LOW AND ROOM TEMPERATURES.

Specimen Number	Solids Composition				Liquid Composition Used for Application		Cycles of Vibration before Failure[a]	Observations Regarding Adhesion
	VA-2 Resin (%)	Filler Type	Filler Amount (%)	Aluminum, Powdered (%)	Solvent	Parts		
1	50	Asbestine 5X	50	0	Cellosolve		1	Coating peeling; not completely dry.
2	50	do.	50	0	Cellosolve Methyl acetate	67 33	3	do.
3	50	do.	50	0	Cellosolve Ethyl acetate	67 33	2	do.
4	50	do.	50	0	Acetone		1 to 5	Corner damaged at start.
5	50	do.	35	15	Cellosolve		4	Separation in center; peeling.
6	50	do.	35	15	Same as 2		1	Coating peeling.
7	50	do.	35	15	Same as 3		>10	Longer drying time than 3.
8	50	do.	35	15	Cellosolve Acetone	67 33	10	
9	40	do.	55	5	Same as 3		5 >5[b]	Longer drying time than 3
10	40	do.	55	5	Ethyl acetate		5 >5[b]	
11	40	do.	55	5	Methyl acetate		5 >5[b]	
12	40	do.	55	5	Acetone		5 >5[b]	
13	35	Bronze, powdered	65	0	Same as 3		>10	
14	35	do.	65	0	Same as 8		2	Corner loose.
15	35	do.	65	0	Same as 2		>10	
16	35	do.	65	0	Cellosolve		>10	Dried several weeks.
17	50	do.	35	15	Same as 3		>10	
18	50	do.	35	15	Benzene		3	
19	50	do.	35	15	Cellosolve		>10	Dried several weeks.
20	50	do.	35	15	Same as 8		10	
21	Bostik M 356 - Applied without prime coat						4	
22	Bostik M 356 - Applied over zinc chromate primer						5 >5[b]	
23	Tuf-On No. 12						5 1[b]	
24	Tuf-On No. 15						5 3[b]	

a. Strips of 0.012 inch aluminum alloy coated with fairing composition were vibrated as cantilever beams at a rate of 1800 r. p. m. and an amplitude of 3 degrees. Vibration at 25° to -65°C for 1 hour and -65° to 25°C for one hour constituted a cycle.

b. Amplitude increased to 5 degrees after 5 cycles at 3 degrees.

TABLE 13. ADHESION OF FAIRING COMPOSITIONS TO ALUMINUM ALLOY DURING ACCELERATED WEATHERING TEST, INCLUDING EXPOSURE TO -50°C.

Specimen No.	Solids Composition						Liquid Composition used for Application[a]		Observations regarding Adhesion
	Plastic		Filler		Filler or Plasticizer				
	Type	Amount %	Type	Amount %	Type	Amount %	Solvent	Parts	
1	VA-2	50	Asbestine 5X	50			Acetone		Adhered throughout test.
2	do.	50	do.	50			Acetone Cellosolve	90 10	do.
3	do.	25	do.	75			Cellosolve Methyl acetate	67 33	do.
4	do.	40	do.	55	Aluminum, powdered	5	Acetone		do.
5	do.	40	do.		do.		Methyl acetate		do.
6	do.	40	do.		do.		Acetone Cellosolve	90 10	do.
7	do.	40	do.		do.		Acetone Cellosolve	33 67	do.
8	do.	40	do.		do.		Ethyl acetate Cellosolve	33 67	do.
9	do.	40	do.		do.		Various; applied over zinc chromate primer		do.
10	do.	50	Zinc oxide, acicular	50			Acetone Cellosolve[b]	90 10	do.
11	do.	50	Zinc oxide, round	50			Acetone Cellosolve[b]	90 10	do.
12	P8	47.5	Asbestine 3X Aluminum, powdered	25 25	Plasticizer DBP	2.5	Ethyl acetate		Edge separated after 36 hr light, 6 hr freezing, 12 hr. fog.
13	CH-2	70.3	Aluminum, powdered	25	Plasticizer TPP	4.7	Acetone Methyl ethyl ketone Diacetone alcohol	40 32 8	Edge separated after 19 hr light, 3 hr freezing, 6 hr fog; complete separation after 172 hr light, 17 hr freezing, 34 hr fog.
14	CH-2	60	do.	25	Plasticizer 84-17	15	Acetone Methyl ethyl ketone Diacetone alcohol	40 32 8	Edge loose after 72 hr light, 9 hr freezing, 18 hr fog.
15	Bostik cement M356						Applied with spatula; no prime coat		Edge loose after 19 hr light, 3 hr freezing, 6 hr fog.
16	do.						Applied over zinc chromate primer		Surface cracks after 54 hr light, 6 hr freezing, 16 hr fog.
17	Tuf-Om No. 12						No prime coat		Adhesion good; chalking after 54 hr light, 7 hr freezing, 14 hr fog.
18	Tuf-Om No. 15						No prime coat		Adhesion good; chalking after 89 hr light, 11 hr freezing, 22 hr fog.

[a]Coatings dried at least 10 days before start of weathering test.

[b]Materials soft at start of weathering test because of retained Cellosolve.

TABLE 14. ADHESION OF FAIRING COMPOSITIONS TO ALUMINUM ALLOY DURING ACCELERATED WEATHERING, INCLUDING EXPOSURE TO -78°C.

Specimen Number	Solids Composition: VA-2 Resin (%)	Solids Composition: Asbestine Filler Type	Solids Composition: Asbestine Filler Amount (%)	Solids Composition: Additional Filler Type	Solids Composition: Additional Filler Amount (%)	Liquid Composition Used for Application: Solvent	Liquid Composition Used for Application: Parts	Observations regarding Adhesion: Applied without Prime Coat	Observations regarding Adhesion: Applied over Zinc Chromate Primer	Flexibility at Room Temperature	Drying Time for Sanding (hr)	Workability
1	40	5x	55	Aluminum, powdered	5	Acetone		Passed	Passed	Good	Approx. 24	Fair
2	40	5x	55	do.	5	Acetone Ether	1 2	Slight separation at edge after 16 hr light, 4 hr fog, 2 hr freeze.	do.	do.	do.	Slightly gumming
3	40	5x	55	do.	5	Ether Toluene Methyl Cellosolve	50 45 5	Slight separation at edge after 85 hr light, 20 hr fog, 10 hr freeze.	do.	do.	>24	Fair
4	40	5x	55	do.	5	Ether Benzene Methyl Cellosolve	50 45 5	Passed	do.	do.	>24	do.
5	15	5x	75	do.	10	Acetone		Edge loose after 17 hr light, 6 hr fog, 3 hr freeze.	Slight separation after 69 hr light, 14 hr fog, 2 hr freeze; failure progressively worse.	Poor, brittle.	Slightly soft 2	Granular
6	15	5x	75	do.	10	Acetone Ether	1 2	Cracked and completely separated after 2 hr fog, 1 hr freeze.	Slight separation after 69 hr light, 14 hr fog, 7 hr freeze.	do.	2	do.
7	24.5	5x	73.5	do.	2	Acetone		Edge separated after 69 hr light, 14 hr fog, 7 hr freeze.	Passed	Good	Slightly soft 2	Fair
8	24.5	5x	73.5	do.	2	Acetone Ether	1 2	Slight separation at edge after 118 hr light, 12 hr freeze, 24 hr fog.	Edge separated after 68 hr light, 14 hr fog, 7 hr freeze.	do.	do.	do.
9	15	5x	75	Gypsum[a]	10	Acetone		Separated 50% after 116 hr light, 24 hr fog, 12 hr freeze.	Passed	Poor, brittle.	2	Lumpy
10	15	5x	75	do.	10	Acetone Ether	1 2	Deep crack observed at end of test.	Deep crack observed at end of test.	do.	2	do.
11	20	5x	60	do.	20	Acetone		Cracked (mechanically) after 22 hr light, 4 hr fog, 2 hr freeze.	Passed	Fair	Slightly soft 3 to 4-1/2	Good
12	20	5x	60	do.	20	Acetone Ether	1 2	Passed	do.	do.	Slightly soft 2	do.
13	23.8	3x	71.4	Zinc dust	4.8	Acetone		Corner separated after 154 hr light, 32 hr fog, 16 hr freeze.	do.	Fair to good.	Slightly soft 3 to 4-1/2	Fair
14	23.8	3x	71.4	do.	4.8	Acetone Ether	1 2	do.	do.	do.	Hard in 2	Good
15	20	3x	55	do.	25	Acetone		Slight edge crack after 2 hr fog, 1 hr freeze.	do.	Fair	Slightly soft 3 to 4-1/2	do.
16	20	3x	55	do.	25	Acetone Ether	1 2	Passed	do.	do.	Hard in 1 to 1-1/2	do.
17	22.7	3x	68.2	Zinc yellow	9.1	Acetone		Separated 70% after 22 hr light, 4 hr fog, 2 hr freeze.	do.	do.	Approx. 24	do.
18	22.7	3x	68.2	do.	9.1	Acetone Ether	1 2	Cracked after 41 hr light, 6 hr fog, 3 hr freeze; loose after 42 hr light, 8 hr fog, 4 hr freeze; broken off after 80 hr light, 16 hr fog, 8 hr freeze.	Edge separated after 2 hr fog, 1 hr freeze.	do.	do.	do.
19	Valentines Nitro-Valspar							Edge loose, specimen cracked after 16 hr light, 4 hr fog, 2 hr freeze.	Cracked and separated 90% after 86 hr light, 18 hr fog, 9 hr freeze; removed primer.	do.	do.	do.
20	Acme Glazing Putty							Edge separated after 17 hr light, 6 hr fog, 3 hr freeze; cracked after 68 hr light, 14 hr fog, 7 hr freeze; separated 50% after 90 hr light, 22 hr fog, 11 hr freeze.	Loose after 2 hr fog, 1 hr freeze; separation more pronounced after 90 hr light, 22 hr fog, 11 hr freeze.	Poor, brittle.	2	do.

a. Commercial gypsum, not hydrated; hydration takes place on exposure.

TABLE 15.- DENSITY OF FAIRING COMPOSITIONS BY WATER DISPLACEMENT METHOD

Composition	Type of sample	Density
Acme glazing putty	Cast	2.9 - 3.3
Bostik M-356	Cast	1.4
Tuf-On No. 12	Cast	2.0
Tuf-On No. 15	Cast	2.0
Valentines Nitro-Valspar	Cast	2.7 - 2.8
40 percent vinyl acetate VA-2 55 percent asbestine 5 percent aluminum, powdered	Molded Cast	1.8 1.0 - 1.4
20 percent vinyl acetate VA-2 55 percent asbestine 25 percent zinc dust	Molded Cast	2.4 2.0

TABLE 16. DATA FOR VARIOUS PLASTICS AND FILLERS FOR USE IN EQUATION II IN COMPOUNDING FAIRING COMPOSITIONS TO OBTAIN DESIRED EXPANSIVITY.

Material	A, Measured[a] (10^{-6}/°C)	$\frac{K}{d}$, Measured[b] (10^6 lb/in^2)	Derived Constants[c] A (10^{-6}/°C)	Derived Constants[c] $\frac{K}{d}$ (10^6 lb/in^2)	Rating of Filler, $\frac{K}{K/d} \times 100$	Description of Pigment Particles
VA-2	75.3[d]			1.77[e]		
VA-3	72.5[d]			2.11[f]		
PS	76.5[d]			1.56[e,f]		
Aluminum, powdered	21.7[d]	4.0		4.0	100	Fine leaf pigment.
Aluminum, filings	21.7[d]	4.0		2.09[h]	52	Irregular random size.
Bronze, powdered		ca. 2.1[i]	16.9[h]	1.86[h]	ca. 89	Leaf pigment; particles are larger than those of aluminum powder.
Carbon, Microonex	5.4[j]	2.65		1.87[k]	70	Very fine; irregular.
Iron, powdered (carbonyl)	11.9[d,l]	3.1		0.33[k]	11	Very fine uniform spherical particles.
Iron, powdered (200 mesh)	11.9[d,l]	3.1		0.50[k]	16	Irregular shapes; random particle sizes.
Magnesium silicate:						Acicular particles; random particle sizes.
Asbestine FT			6.6-7.4[h]	2.24-2.31[h]		
Asbestine 5X			5.8-7.4[h]	3.06-3.37[h]		
Asbestine 3X			7.4-9.6[h]	2.40-2.70[h]		
Asbestine (average)			7.4	2.66		
Quartz, fused, powdered	0.3[m]	2.48		1.80[k]	73	Very fine irregular particles; random particle size.
Silica, powdered		1.99	9.4[h]	1.45[h]	73	300 Mesh and finer; irregular particle size.
Zinc dust	26.4[j]	1.22		0.54[k]	45	Irregular ellipsoids and spheres.
Zinc yellow			25.6[h]	1.65[h]		Very fine round particles.

a. Where not otherwise indicated, expansivities apply to the temperature range -50° to 0°C.
b. Calculated from compressibilities (1/K) and densities (d) taken from International Critical Tables.
c. Calculated by the use of equation II with data from tables 6 and 8.
d. Expansivity measured by authors. Value for VA-2 is average for three batches.
e. Calculated by equation II from data for mixtures of resin and aluminum powder in tables 6 and 8.
f. Calculated by equation II from data for mixtures of resin and asbestine in tables 6 and 8.
g. Measured on a specimen of polystyrene PS which was dissolved in ethyl acetate and then baked for 16 hr at 105°C to remove solvent.
h. Calculated by equation II from data for mixtures of VA-2 and filler in tables 6 and 8.
i. Estimated for primer gilding bronze, 97% Cu, 2.97% Zn, .01% Pb, .02% Fe.
j. Data reported in Chemistry and Physics Handbook.
k. Calculated by equation II from data for 50-50 mixtures of VA-2 and filler, using coefficient of thermal expansion given in column 2.
l. Measured for cold-rolled steel for temperature range -40° to 0°C.
m. Data reported in N.B.S. Scientific Paper No. 524

TABLE 17. COMPARISON OF CALCULATED VALUES WITH MEASURED EXPANSIVITIES OF THREE COMPONENT MIXTURES.

Specimen Number	Composition						Expansivity, -50° to 0°C ($10^{-6}/^{\circ}$C)	
	Resin		Fillers					
	Type	Amount (%)	Type	Amount (%)	Type	Amount (%)	Calculated	Measured
1	VA-2	50	Asbestine 5X	35	Aluminum, powdered	15	33.1 to 35.5	36.0
2	do.	40	do.	55	do.	5	25.8 to 26.9	27.7 to 28.1
3	do.	30	do.	65	do.	5	21.5 to 23.2	20.3
4	do.	15	do.	75	do.	10	14.9 to 17.1	14.4
5	do.	20	do.	60	Zinc dust A	20	17.5 to 20.1	20.5
6	do.	20	do.	55	do.	25	18.4 to 21.1	20.8 to 20.9
7	do.	20	do.	45	do.	35	20.8 to 23.3	22.4
8	do.	40	Asbestine 3X	55	Aluminum, powdered	5	28.9 to 30.2	27.9
9	do.	25	do.	75	Zinc dust A	5	19.8 to 21.4	21.0
10	do.	20	do.	50	Zinc dust B	30	19.7 to 22.0	21.4
11	do.	20	do.	55	Zinc dust B	25	21.1 to 23.7	21.9 to 23.5
12	do.	20	do.	55	Zinc dust C	25	21.1 to 23.7	21.6
13	do.	28.7	do.	68.2	Zinc yellow	9.1	20.0 to 21.6	21.4
14	do.	50	Bronze, powdered	35	Aluminum, powdered	15	42.4	42.4
15	do.	35	do.	50	do.	15	35.0	36.1
16	VA-2 PS	38 2	Asbestine 5X	55	do.	5	27.6 to 28.8	29.8
17	VA-3	24.5	Asbestine FT	73.5	do.	2	21.0 to 22.6	20.0 to 20.2
18	do.	40	Asbestine 3X	55	do.	5	30.5 to 31.9	29.8

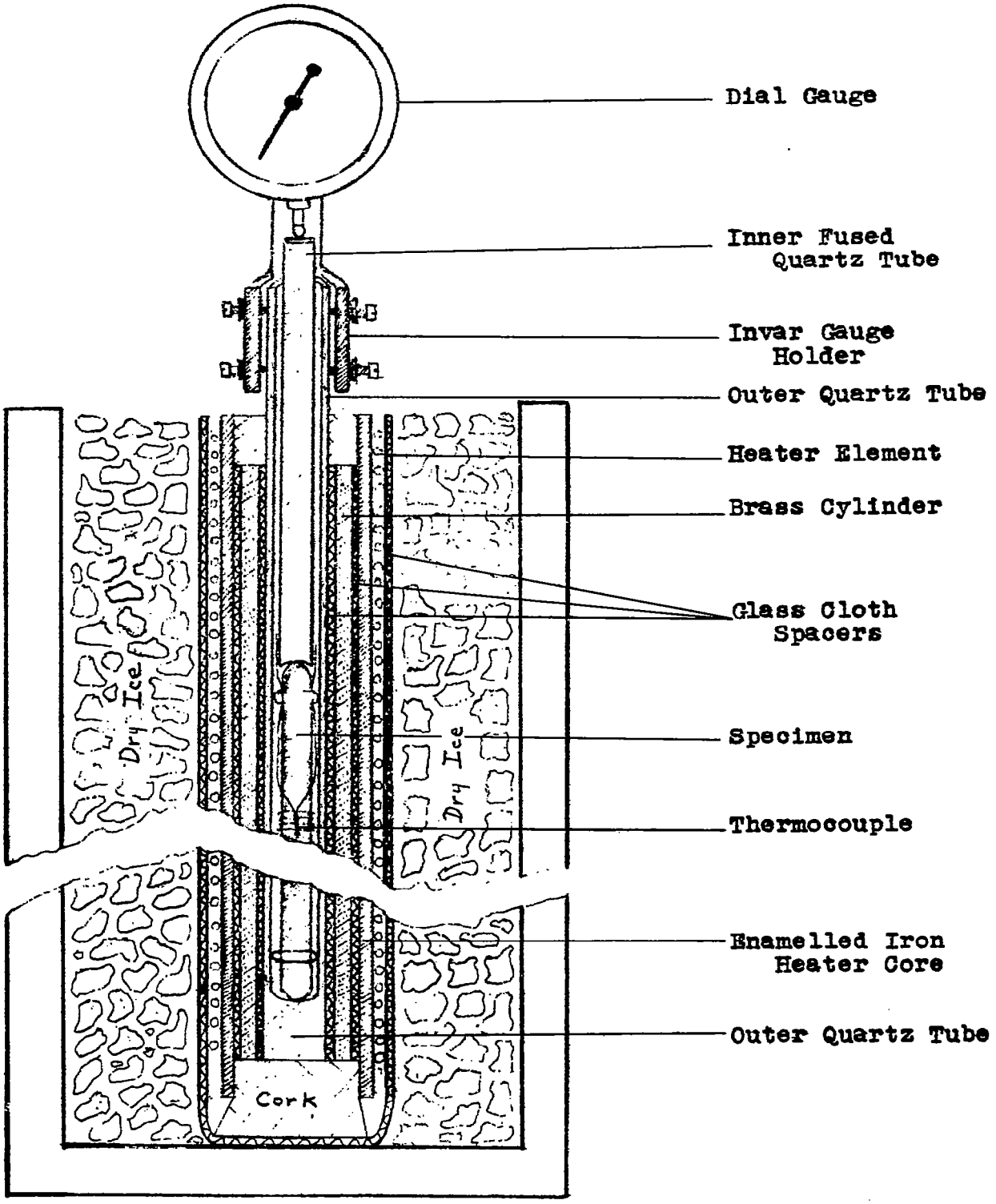

Figure 1. Thermal Expansion Apparatus

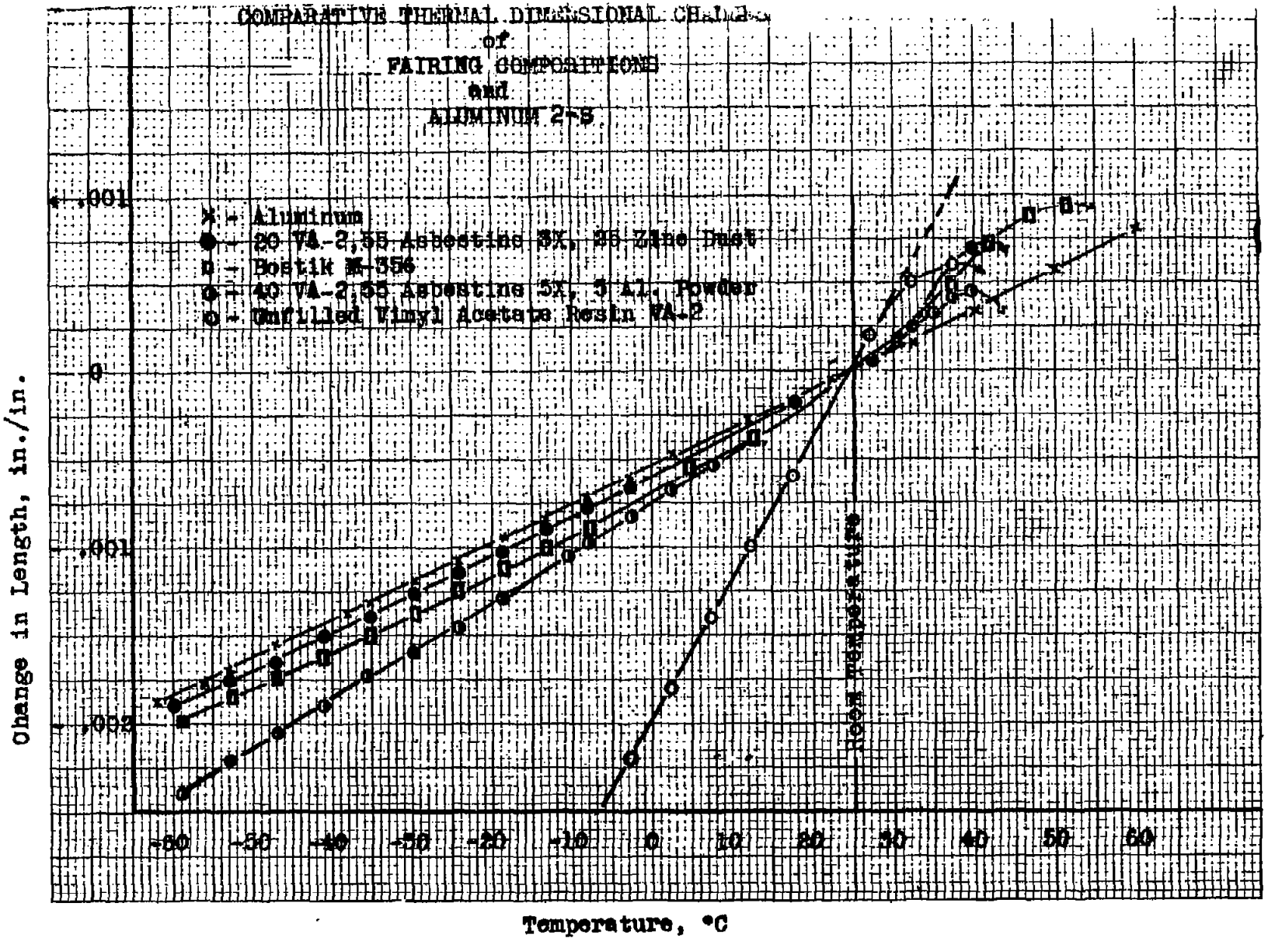
COMPARATIVE THERMAL DIMENSIONAL CHANGE
of
FAIRING COMPOSITIONS
and
ALUMINUM 2-S
X - Aluminum
● - 20 VA-2,55 Asbestine 3X, 25 Zinc Dust
□ - Bostik M-356
◐ - 40 VA-2,55 Asbestine 3X, 3 Al. Powder
○ - Unfilled Vinyl Acetate Resin VA-2
+.001
0
-.001
-.002
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
Room temperature
Change in Length, in./in.
Temperature, °C

Figure 2

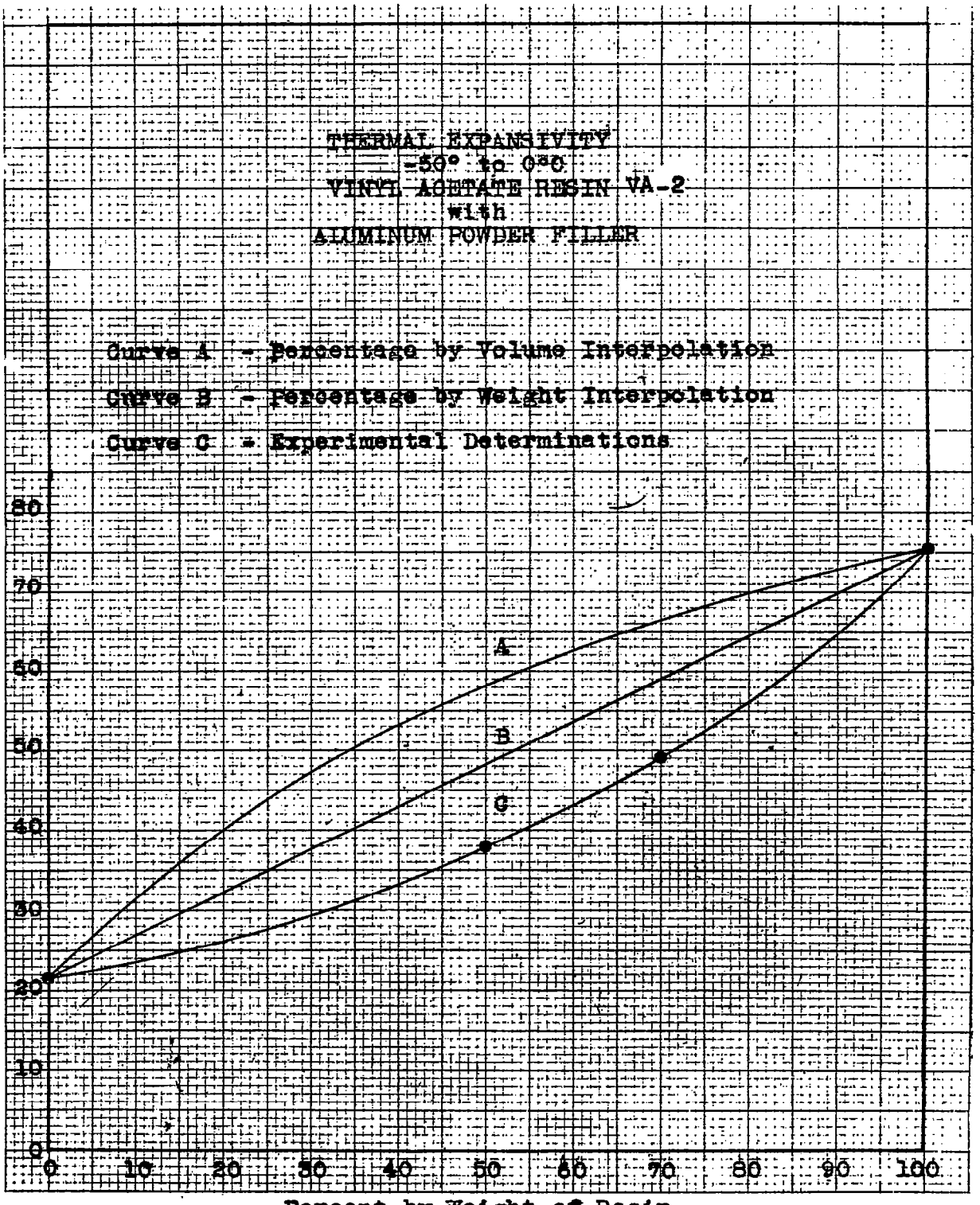
THERMAL EXPANSIVITY
-50° to 0°C
VINYL ACETATE RESIN VA-2
with
ALUMINUM POWDER FILLER
Curve A - Percentage by Volume Interpolation
Curve B - Percentage by Weight Interpolation
Curve C - Experimental Determinations
Expansivity, 10^{-6}/°C
Percent by Weight of Resin
A
B
C
0
10
20
30
40
50
60
70
80
90
100

Figure 3

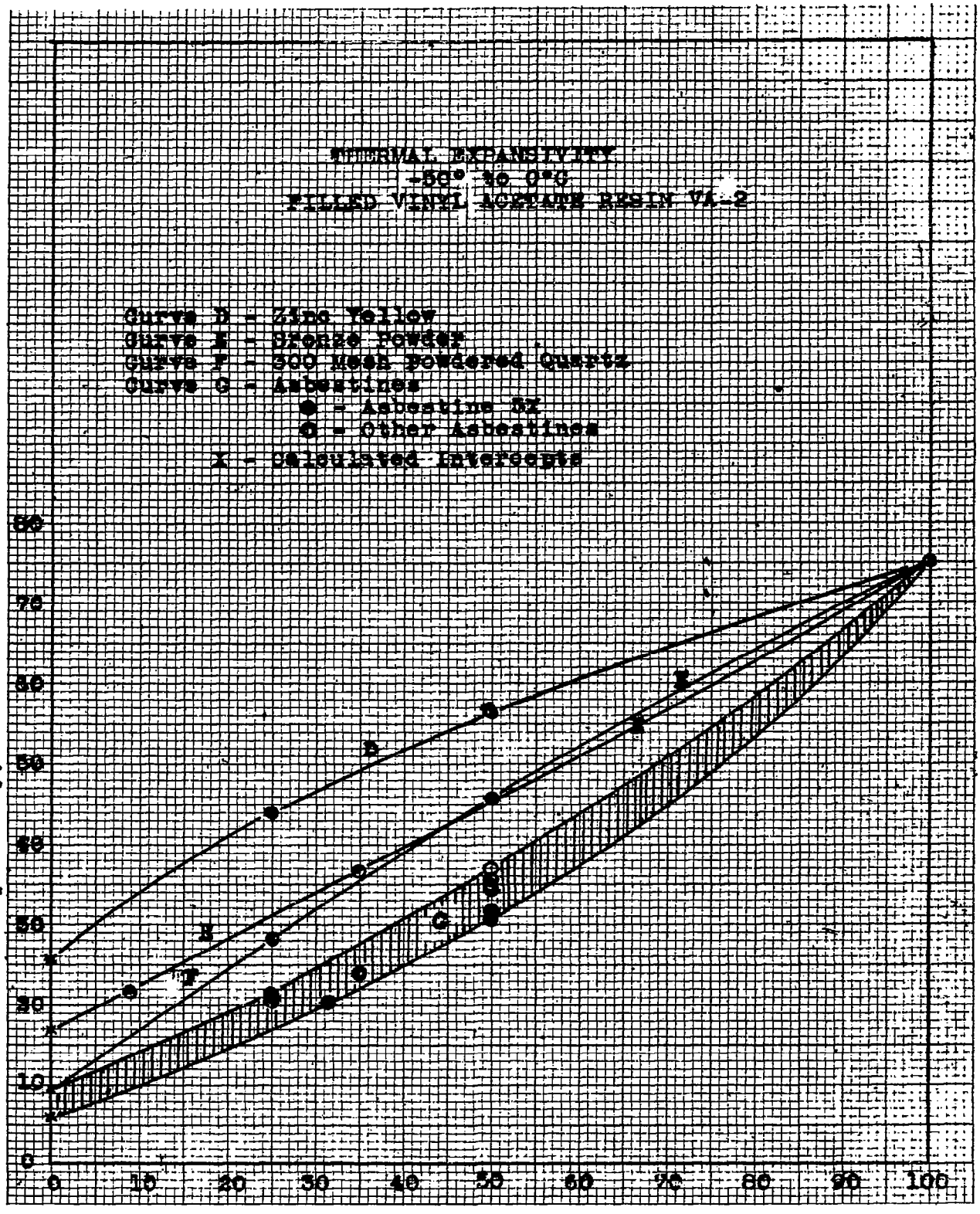
THERMAL EXPANSIVITY
-50° to 0°C
FILLED VINYL ACETATE RESIN VA-2
Curve D - Zinc Yellow
Curve E - Bronze Powder
Curve F - 300 Mesh Powdered Quartz
Curve G - Asbestines
● - Asbestine 5X
○ - Other Asbestines
X - Calculated Intercepts
Expansivity, 10^{-5}/°C
Percent of Resin
0
10
20
30
40
50
60
70
80
90
100
D
E
F
G

Figure 4

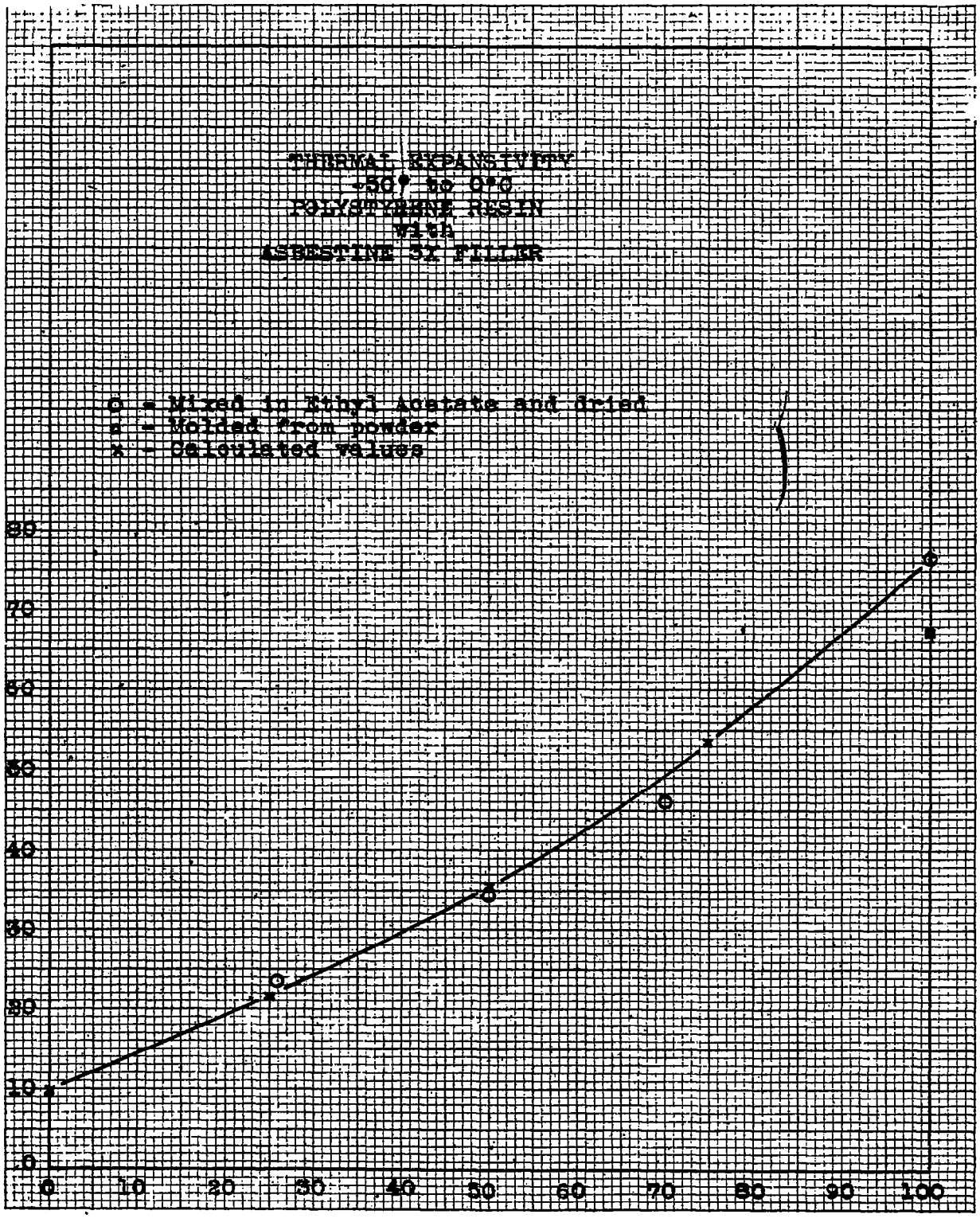
THERMAL EXPANSIVITY
-50° to 0°C
POLYSTYRENE RESIN
With
ASBESTINE 5X FILLER
○ - Mixed in Ethyl Acetate and dried
□ - Molded from powder
× - Calculated values
Expansivity, 10⁻⁶/°C
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Percent of Resin

Figure 5